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Survivability and Deterioration of Fire-Injured Trees in the Northern Rocky Mountains : A Review of the Literature

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Introduction

The wildfire season of 2000 will be recorded as one of the most widespread and damaging in recent history. As such, it will unquestionably have both short- and long-term effects on management activities in forested stands of the intermountain West. Some of those effects may be initiation of bark beetle or other insect outbreaks. In some cases, existing outbreaks may be prolonged. It will be important to determine to the extent possible which trees are likely to succumb to fire damage, which might survive fire effects but be killed by bark beetles, and which others may be more susceptible to fungal infection and degradation. The sooner those assessments can be made and preventive or corrective measures implemented, the more successfully adverse effects or economic loss will be avoided.

Research conducted in the Northern Rocky Mountains within the past two decades can make prognoses of tree survival and appropriate management responses more effective. Ryan (1982, 1989) has shown that trees survive the effects of fire in relation to damage to crown, stem, or roots. Further, the amount of damage individual trees can sustain and still survive is dependent upon characteristics of its species (needle length and bark thickness), its size (diameter and height), and site factors on which it is growing. Research by Ryan, Harrington and Reinhardt has provided helpful means of predicting post-fire mortality based on species-specific characteristics (Ryan and Amman 1994, Harrington 1996, Reinhardt and Ryan 1989).

In some cases, effects and management responses to earlier fires have served as valuable information sources. This report includes a summary of pertinent research results, useful historic precedents, and work involving alternatives considered and management activities implemented during previous post-fire evaluations. Recommendations developed will have to be general enough to have widespread applicability. At the same time, they are subject to site-specific conditions often difficult to predict, such as post-fire weather over the following year or two and those effects on insects and their hosts.

Some of the more extensive and intensely affected areas are forested stands, of all ownerships, in southwest Montana; but significant fire damage was experienced on more than 700,000 acres Statewide. Other states in the intermountain West have been similarly impacted. Into mid-September, many fires were still active, and affected acres continued to increase. Still, there was a need to begin the process of addressing fire effects—how both short- and long-term management decisions might be affected; and how insect and disease interactions with fire-damaged trees and stands might influence those decisions.

Insect Considerations

While wood-boring insects of several types may be attracted to fire-damaged trees, most questions pertain to overall tree survivability and likelihood of bark beetle outbreaks developing in fire-weakened trees. Bark beetle outbreaks following wildfires are not unprecedented, but neither are they certain. Several conditions must exist for bark beetles to take advantage of fire-damaged hosts. First, there must be a sufficient supply of undamaged inner bark in fire-affected trees. If the beetles' food supply, the inner bark (phloem), becomes dry and darkened—often the case with stand-replacing fires or in thin-barked tree species—beetles can neither feed nor deposit eggs in it. Second, fires must occur at a time when beetles are in the adult stage and can quickly infest susceptible trees. Fires in late summer or early fall may occur after beetles have flown. A recently killed tree's inner bark remains usable to beetles for a relatively short time. If not attacked while still "green," phloem may become too dry, or in some cases "sour," before the next flight season. And third, there must be a population of beetles within a reasonable distance to take advantage of weakened trees which become available. Because all three conditions must be met for an outbreak to develop, beetle epidemics following wildfires are not a foregone conclusion. Still, a few such outbreaks are well documented in the Northern Region. Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), spruce beetle (*D. rufipennis* [Kirby]), and pine engraver beetle outbreaks following wildfires in 1988 and 1994 became extensive and quite damaging in parts of Montana and in Yellowstone National Park (Amman and Ryan 1991; Rasmussen et al. 1996; Ryan and Amman 1996; FHP, Northern Region, unpublished office reports).

Following the 1988 Yellowstone National Park fires, Amman and Ryan (1991) concluded "The 1988 fires in the Greater Yellowstone Area killed many trees outright. Many more were subjected to sublethal injuries resulting in increased susceptibility to insect attack. Still other trees escaped fire injury but are exposed to the spread of insect attack from nearby injured trees." A follow-up report, by Rasmussen et al. (1996), showed "that bark beetle and delayed tree mortality due to fire injury significantly alter mosaics of green and fire-injured trees, that insect infestation increases with the percent of basal circumference killed by fire, and that bark beetle populations appear to increase in fire-injured trees and then infest uninjured trees."

Ryan and Reinhardt (1988) demonstrated that post-fire mortality can be predicted as a function of crown scorch and bark thickness for most western conifers. Their studies concluded that probability of mortality increased with percentage of crown killed and decreased as bark thickness increased. Weatherby et al. (1994) used those relationships in an effort to evaluate tree survivability following the Lowman (Idaho) fire of 1989. In their study area, 82% of the ponderosa pine and 52% of the Douglas-fir survived the fire; but a significant portion of the trees which died, were killed by bark beetles as opposed to direct fire effects. In fact, they noted that many larger diameter trees predicted to survive the fire were subsequently killed by Douglas-fir beetles.

Observations made following wildfires in western Montana have shown that Douglas-fir, particularly, is likely to be killed by Douglas-fir beetles if half or more of the bole circumference has been charred to the extent that cambium was killed. Occasionally, that damage can be somewhat inconspicuous if it occurs to large, lateral roots at or below the duff layer. Amman and Ryan (1991) showed that 71% of the Douglas-fir on their Yellowstone plots died—over twice as many as predicted by the model using crown scorch and bark thickness characteristics. They surmised, “A possible explanation is that Douglas-fir tends to have large lateral roots near the soil surface that are often injured by fires. Thus, unmeasured root injury may have contributed to the higher than expected mortality. However, because several of the dead Douglas-firs received minimal heating, insects appear to be responsible for part of the additional mortality.”

Other tree species have experienced significant amounts of mortality, as well; often a combination of fire effects and subsequent bark beetle infestations. Ryan and Amman (1996) showed that following the Yellowstone Park fires of 1988, in their survey area 77% of the Douglas-fir; 61% of the lodgepole pine; 94% of the Englemann spruce and 100% of the subalpine fir had been killed by a combination of fire injury and/or bark beetles.

Previous post-fire evaluations in the Northern Region have varied somewhat from area to area, but most are similar to ones developed following the Little Wolf Fire (Tally Lake RD, Flathead NF) in 1994. Fire-affected forested areas were assigned “burn intensity” categories using aerial photographs taken soon after the fire and a knowledge of pre-fire stand conditions. They were refined by post-fire surveys and field verification within burned areas. Ground-char classes were based on ones described by Ryan and Noste (1985). Burn intensity (BI) classes were as follows:

> **BI 1**: All vegetation blackened--foliage destroyed, boles deeply charred and understory vegetation burned. Approximate distribution of ground char: Unburned 0%, Light 15%, Moderate 70%, Deep 15%.
>
> **BI 2**: Stems predominantly blackened, some foliage only scorched. Understory vegetation mostly burned. Ground char: Unburned 0%, Light 25%, Moderate 60%, Deep 15%.
>
> **BI 3**: Most vegetation scorched with few blackened stems; small amounts of green vegetation. Ground char: Unburned 0%, Light 40%, Moderate 50%, Deep 10%.
>
> **BI 4**: Predominantly, but temporarily green with scorched or blackened areas. Ground char: Unburned 15%, Light 65%, Moderate 15%, Deep <5% (Anonymous 1996).

In order to help define the likelihood of bark beetle or other insect population buildups in those areas, we made the following assessments according to the identified burn intensity categories (Gibson 1994):

BI 1: Few severely burned trees will be infested by insects which will later damage uninjured trees. Some trees may attract wood wasps (horntails, family Siricidae) or wood borers in the beetle families Cerambycidae (longhorned beetles or roundheaded wood borers) and Buprestidae (flatheaded or metallic wood borers) but they are of little threat to adjacent green trees. Where charring has destroyed or dried the phloem, no bark beetle food remains. Even most wood borers which ultimately feed within the sapwood, require relatively fresh inner bark for newly hatched larvae. Thin-barked tree species burned to the extent that inner bark is destroyed will provide little food for insects. Thicker barked species may attract some wood-inhabiting insect species, depending on depth and height of charring.

BI 2: Some of the thicker barked species—such as Douglas-fir, western larch and ponderosa pine—may survive immediate effects of the fire. In the case of Douglas-fir, however, bole scorch on more than about half of the tree's circumference will likely produce a strong attraction for Douglas-fir beetles. Large-diameter, and older ponderosa pines in this category may be attacked by western pine beetles (*D. brevicomis* LeConte), or red turpentine beetles; however, "outbreak" development of these beetles in this situation would not be expected. Severely weakened western larch may be infested by several species of wood borers. Thin-barked species in this group—lodgepole pine, Engelmann spruce, and subalpine fir—may have been burned too severely to attract bark beetles or wood borers.

BI 3: This group likely will attract the most bark beetles. Douglas-fir in this category may be less affected, depending upon degree of bark and root collar scorch, as noted earlier. Most second-growth ponderosa pine, lodgepole pine, Engelmann spruce and subalpine fir will almost certainly be attacked by bark beetles or wood borers. Smaller diameter ponderosa pines and lodgepole pines will be infested by one or more species of engraver beetles (*Ips* spp.), other secondary bark beetles (*Pityogenes* spp. and *Pityophthorus* spp.) and wood-boring beetles. We have learned that mountain pine beetles are seldom attracted to fire-weakened trees. Engelmann spruce will be attacked by spruce beetles and subalpine fir will support populations of several beetles, the most dominant being western balsam bark beetle (*Dryocoetes confusus* Swaine).

BI 4: In this latter group, the amount of bark beetle attraction will be dependent mostly upon amount of root collar damage. Most Douglas-fir, western larch and ponderosa pines will survive and not attract beetles unless smoldering ground fires significantly damaged roots or root collars. Other tree species are more likely to be infested, even though severe damage may not be readily apparent. Observations in other burned areas have shown thin-barked trees can withstand only a small amount of damage at ground level without becoming so weakened they eventually succumb to bark beetle attacks. In these areas, it is common to find trees with little apparent bole or crown damage that have been completely girdled at the root collar.

Beyond the likelihood of individual trees dying directly from fire damage, there is great interest in determining which trees are at risk of attracting fatal populations of bark beetles—both dependent upon, and independent from, fire effects. Ryan and Reinhardt (1988) have described the survivability of seven coniferous species, relative to crown scorch and bark thickness. While their work did not address all species encountered in the intermountain West—exceptions being ponderosa pine and grand fir—they have provided the basis for developing criteria which could define the probability that any particular tree species, or individual tree, would survive fire injury. As noted previously, some trees "predicted" to survive, based on their model, might be subsequently attacked by bark beetles. On the other hand, trees killed outright, or which have a high probability of death, may be too severely damaged to be infested by bark beetles.

Fire Survivability of Common Coniferous Species in the Intermountain West

Douglas-fir: Reporting results from a multi-year, post-fire study in the Greater Yellowstone Area, Ryan and Amman (1996) showed that 4 years following the fires, 79% of 125 Douglas-fir in their survey plots had been attacked by one or more species of insects, and 77% were dead. Seventy-one percent of the insect attacks were by Douglas-fir beetles. Dead trees had suffered greater crown scorch and bole injury; however, trees attacked by Douglas-fir beetles had more than 50% basal girdling, ample green phloem, and less than 75% crown scorch. Beetles initially attacked severely injured trees, then attacked more lightly injured trees in subsequent years. Mortality immediately following the fires occurred in trees with both severe crown scorch and bole injury. The majority of subsequent mortality, however, was found in trees with little crown injury but more than 50% basal girdling. Of the dead Douglas-fir, 83% had been infested by insects. In a similar survey of fire-damaged trees in central Idaho, Weatherby, et al (1994) showed that Douglas-fir which died from fire effects had 74% crown scorch, whereas those that were killed by beetles had 39% crown scorch.

Ponderosa Pine: Burns and Honkala (1990) noted, "Survival and growth of ponderosa pine usually are little affected if 50 percent or less of the crown is scorched in a fire. Six years after a fire in Arizona, however, no poles and only 5 percent of the sawtimber-size trees were living if more than 60 percent of the crown had been destroyed. Low tree vigor and cambium damage increase the likelihood of mortality." Wagener (1961) noted that extent of fire damage in ponderosa pines was at least partly a function of time of burn. Early season fires were more damaging than ones which occurred in late summer or early autumn. Likewise, time of year greatly affected subsequent bark beetle activity; and both directly affected a tree's probability of survival. He showed young, fast-growing trees on good sites were more likely to survive than old, overmature trees on poor sites. He also noted that trees with complete crown scorch will likely survive if buds and twigs are not damaged extensively and are thus capable of producing foliage the following year. An additional criterion was damage to bark and cambium—trees with both heavy foliage scorching and moderate to severe cambium kill were more likely to die later from bark beetle attacks. Though mature ponderosa pine has thick, fairly fire-resistant bark; permanent damage and death will be influenced by amount and distribution of fuels on the forest floor and other site and stand conditions. In uneven-aged stands, injury to the cambium will vary considerably from site to site. Resultant cambium damage will greatly determine tree's survivability, and cambium killing which extends for more than a few feet up the trunk will significantly reduce a tree's probability of survival. In their study, Weatherby et al. (1994) showed that few ponderosa pines greater than 4 inches d.b.h. died if crown scorch was less than 80%.

Lodgepole Pine: According to Burns and Honkala (1990), lodgepole pine is more susceptible to fire than Douglas-fir and some of its other associates, because of its relatively thin bark. But it is less susceptible to fire than either Engelmann spruce or subalpine fir. On the other hand, the success of lodgepole pine is directly affected by the role fire plays in its regeneration. Overmature lodgepole pine's susceptibility to mountain pine beetle, a beetle-killed stand's proclivity to burn, and fire's role in opening serotinous cones, has made the lodgepole pine/mountain pine beetle/fire/stand replacement cycle a well-established relationship throughout the tree's range. Although attracted to over-mature and slow-growing individuals, mountain pine beetles have shown little attraction to fire-damaged lodgepole pine. Ryan and Amman (1996) showed of 151 lodgepole pine surveyed, 62% were attacked by insects and 61% (of the total) had died. Most dead trees had been extensively girdled by fire (greater than 75% of bole circumference) and had been infested by beetles. The majority of the beetles were engraver beetles (*Ips* spp.); but a few had been infested by secondary bark beetles, or wood borers. Engraver beetles preferentially attacked trees with more than 75% basal girdling, but less than 50% crown scorch.

Engelmann Spruce: Probably because of their typically wetter habitats, less fire-effects studies have been done in Engelmann spruce stands than many other species. In their study following the 1988 fires in Yellowstone National Park, Ryan and Amman (1994) found only 17 spruce on their plots. By 1991, 83% of them were dead. They noted that as might be expected for thin-barked species, mortality did not vary by tree diameter. Trees which received the most apparent damage, in the form of crown and bole injury, were the ones most likely to die. Sixteen of the 17 trees had been more than 90% girdled by fire and 82% of them had been infested by spruce beetles. In addition, because spruce are a shallow-rooted species, slow-burning fires causing significant root damage create trees which are easily windthrown. In turn, windthrown spruce on which there is little bole charring are quite likely to be infested by spruce beetles.

Subalpine Fir: Ryan and Amman (1994) noted that subalpine fir are known for their lack of fire resistance, primarily because of their thin bark. They commented, "Virtually any fire vigorous enough to scorch the bark will cause cambium injury, followed by sloughing of the dead bark." In their study they found 17 subalpine fir, all of which died following the fires. Eighty-eight percent were eventually infested by woodborers, although bark damage was initially significant enough to preclude bark beetle infestations. We have noticed, however, subalpine fir with root damage is easily windthrown, as previously noted for spruce. Such trees, with little additional bole damage, are quite susceptible to western balsam bark beetles. Beetle populations building in downed trees are then likely to infest nearby green trees not affected by fires (Personal observations and unpublished data).

Western Larch: Ryan and Reinhardt (1988) described conditions most often affecting tree survivability following prescribed burns. They concluded that coniferous species in the northwestern United States vary widely in their resistance to fire injury, and that deeper-rooted trees tend to have thicker bark which renders them relatively resistant to fire-related damage. Burns and Honkala (1990) recorded, "Larch develops a deep and extensive root system…" and further, "Mature larches are the most fire-resistant trees in the Northern Rockies because of their thick bark, their high and open branching habit, and the low flammability of their foliage." Mature western larch are at once relatively fire resistant, wind firm, and have few insect pests—particularly bark beetles—which take advantage of weakened individuals or stands. Younger larch, with thinner bark and growth habits, may be more susceptible to fire injury; especially cambial damage and crown scorch, as described by Ryan and Reinhardt (1988).

Grand Fir: Little fire-effect research has been conducted in grand fir stands; however, its morphological characteristics are similar to white fir which is rated moderate in fire resistance, becoming more resistant as it ages. In both species, fire injuries may provide entry courts for significant decay organisms. Burns and Honkala (1990) rate grand fir as "medium" in fire resistance—less resistant than larch, ponderosa pine and Douglas-fir; but more resistant than subalpine fir and spruce. They note that its resistance to fire is based largely on habitat. On moister sites it is readily killed by ground fires. On drier sites grand fir is more fire resistant due to deeper root systems and thicker bark which develop in those environments.

Fire Survivability: A Case Study

Weatherby (1999) established a study to follow the fate of selected trees in two areas burned in 1994 on the Payette National Forest, ID. Part of a five-year study, the following table shows results after four years (fifth year data has been collected but not yet summarized). Her work illustrates the feasibility of predicting survivability based on diameter (at breast height), percent crown scorch, and percent of circumference of bole (or roots) charred. Results of her 4-year observations were:

Grand fir (French Creek)—121 trees in survey:

DBH	% Crown Scorch	% Circum Bole/Root Char	After 4 years:
≥20 in	75 and greater		No trees in category
≥20 in	Less than75	50 and greater	10 dead/18 alive
≥20 in	Less than75	Less than 50	0 dead/ 4 alive
<20 in	50 and greater		6 dead/1 alive
<20 in	Less than 50	50 and greater	33 dead/28 alive
<20 in	Less than 50	Less than 50	1 dead/20 alive

Douglas-fir (French Creek)—82 trees in survey:

DBH	% Crown Scorch	% Circum. Bole/Root Char	After 4 years:
≥24 in	40 and greater		No trees in category
≥24 in	Less than 40	50 and greater	0 dead/1 alive
≥24 in	Less than 40	Less than 50	0 dead/2 alive
<24 in	66 and greater		No trees in category
<24 in	Less than 66	50 and greater	9 dead/ 49 alive
<24 in	Less than 66	Less than 50	2 dead/19 alive

Douglas-fir (Pony Creek)—174 trees in survey:

DBH	% Crown Scorch	% Circum. Bole/Root Char	After 4 years:
≥24 in	40 and greater		18 dead/0 alive
≥24 in	Less than 40	50 and greater	1 dead/3 alive
≥24 in	Less than 40	Less than 50	3 dead/6 alive
<24 in	66 and greater		25 dead/11 alive
<24 in	Less than 66	50 and greater	10 dead/48 alive
<24 in	Less than 66	Less than 50	6 dead/43 alive

Ponderosa Pine (Pony Creek)—44 trees in survey:

DBH	% Crown Scorch	% Circum. Bole/Root Char	After 4 years:
≥20 in	80 and greater		1 dead/1 alive
≥20 in	Less than 80	75 and greater	1 dead/2 alive
≥20 in	Less than 80	Less than 75	3 dead/22 alive
<20 in	66 and greater		1 dead/0 alive
<20 in	Less than 66	75 and greater	1 dead/0 alive
<20 in	Less than 66	Less than 75	0 dead/12 alive

Summarizing the above data shows in the first area (French Creek), of 121 grand fir and 82 Douglas-fir monitored following the 1994 wildfire, 41% of the grand fir and 13% of the Douglas-fir had died. Examinations revealed 44% of the dead grand fir and 45% of the dead Douglas-fir had been killed by bark beetles. In the second area (Pony Creek), 36% of the Douglas-fir and 16% of the ponderosa pine had died through 1998. Bark beetles killed slightly more than two-thirds of the dead Douglas-fir (67%) and one-fourth (27%) of the dead ponderosa pines.

Summary

Much remains to be learned before we will be able to accurately predict which trees will succumb to the effects of a wild or prescribed fire, which will survive, and which of those may ultimately be killed by bark beetles. Some of the more severely affected trees will unquestionably die; some of the least affected will no doubt survive. Trees between the two extremes are ones most difficult to predict because of their varying susceptibility to bark beetles, the effects of post-fire weather, and other site/stand factors difficult to measure and not well-understood. As previously noted, susceptibility to bark beetles is determined by (1) amount of damage and a tree's response to it, (2) populations of bark beetles in the vicinity of damaged trees, (3) weather for several months to several years prior to and following the fire, and (4) time of year fire occurs. In addition, a complex of factors—some more fully understood than others—are involved in a tree's survivability. Not the least of those are its pre-fire physiological condition, an array of abiotic site factors, a host of potentially damaging biotic agents, and interactions between all of them.

Realistically, we will never unfailingly predict either post-fire survival or death for all trees. But reasonably reliable estimates, sufficient for most management decisions, are possible if all parameters we can measure are adequately considered.

In conclusion, because of the area burned throughout the West in 2000—final tally may exceed six million acres—dealing with fire effects on all affected resources will undoubtedly extend well into the foreseeable future. Yet the need to assess as quickly as possible where site rehabilitation and stabilization is most critical, and in some cases where economic values can be captured in a timely manner, will be paramount.

In one example, Gibson et al. (1999) documented buildups of both spruce beetle and Douglas-fir beetle populations following a wildfire, and expedient management responses used to forestall significant outbreaks on the Flathead National Forest, MT. In dealing with most bark beetle populations, and wood borers as well, timing of treatments is important. Dependent upon time of burn, damaged trees may be infested from shortly after fires are out (within a few days) until trees either recover or phloem becomes unsuitable (as long as 1-2 years post-burn). Some treatments, such as the use of anti-aggregative pheromones, may provide critical protection for injured trees until beetle populations decline or tree vigor improves. (As of October 2000, the only operational bark beetle anti-aggregant is MCH [methylcyclohexanone], used to protect Douglas-fir from attack by Douglas-fir beetle. We are hopeful continuing research will provide ones useful against other bark beetle species in the near future.) In determining what actions may be most appropriate, an estimate of tree survivability and susceptibility to bark beetles, other insects, or deleterious effects of pathogens will be essential. We hope this information will be helpful in those on-going efforts.

References

Anonymous. 1996. Environmental assessment, spruce beetle control project. U.S. Department of Agriculture, Forest Service, Flathead National Forest, Tally Lake Ranger District. 203 p.

Amman, G.D.; Ryan, K.C. 1991. Insect infestation of fire-injured trees in Greater Yellowstone Area. Research Note INT-398. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Burns, R.M.; Honkala, B.H. (Technical Coordinators). 1990. Silvics of North America, Volume 1, Conifers. Washington, D.C.: Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service. 673 p.

Gibson, K.E. 1994. Trip Report, Tally Lake RD, October 17, 1994. Unpublished office report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Gibson, K.; Lieser, E.; Ping, B. 1999. Bark beetle outbreaks following the Little Wolf Fire, Tally Lake Ranger District, Flathead National Forest. FHP Report 99-7. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 15 p.

Harrington, M.G. 1996. Fall rates of prescribed fire-killed ponderosa pine. INT-RP-489. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p.

Rasmussen, L.A.; Amman, G.D.; Vandygriff, J.C.; Oakes, R.D.; Munson, A.S.; Gibson, K. E. 1996. Bark beetle and wood borer infestation in the Greater Yellowstone Area during four postfire years. Research Paper INT-RP-487. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Reinhardt, E.D.; Ryan, K.C. 1989. Estimating tree mortality resulting from prescribed fire. In: Symposium proceedings: Prescribed fire in the Intermountain Region. D.M. Baumgartner, D.W. Breuer, B.A. Zamora, L.F. Neuenschwander, and R.H. Wakimoto (eds.). Pullman, WA: Washington State University: 41-44.

Ryan, K.C. 1982. Evaluating potential tree mortality from prescribed burning. In: Symposium proceedings, Site preparation and fuels management on steep terrain. D.M. Baumgartner (ed.). Pullman, WA: Washington State University: 176-179.

Ryan, K.C. 1989. Predicting prescribed fire effects on trees in the Interior West. In: Symposium proceedings: The art and science of fire management. M.E. Alexander and G.F. Bisgrove (Tech. Coords). Information Report NOR-X-309. Edmonton, Alberta, Canada: Northern Forestry Centre: 148-162.

Ryan, K.C.; Amman, G.D. 1994. Interactions between fire-injured trees and insects in the Greater Yellowstone Area. In: Plants and their environments, proceedings of the first biennial scientific conference of the Greater Yellowstone ecosystem. D.G. Despain (ed.). Technical Report NPS/NRYELL/NRTR/93XX. Denver, CO: U.S. Department of the Interior, National Park Service: 259-271.

Ryan, K.C.; Amman, G.D. 1996. Bark beetle activity and delayed tree mortality in the Greater Yellowstone Area following the 1988 fires. In: Proceedings, Ecological implications of fire in Greater Yellowstone. R.E. Keane, K.C. Ryan, S.W. Running (eds.) Int. Assoc. Wildland Fire, Fairfield, WA: 151-158.

Ryan, K.C.; Noste, N.V. 1985. Evaluating prescribed fires. In: Proceedings, Symposium and workshop on wilderness fire. J.E. Lotan et al.(eds.). General Technical Report INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 230-238.

Ryan, K.C.; Reinhardt, E.D. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research 18:1291-1297.

Wagener, W.W. 1961. Guidelines for estimating the survival of fire-damaged trees in California. Miscellaneous Paper No. 60. Berkeley, CA. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 p.

Weatherby, J.C.; Mocettini, P.; Gardner, B.R. 1994. Biological evaluation of tree survivorship within the Loman Fire boundary, 1989-1993. Report No. R4-94-06. Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Region. 10 p.

Weatherby, J. 1999. Inter-office memo: J. Weatherby to Forest Supervisor, Payette National Forest (dated January 20, 1999). Boise, ID: U.S. Department of Agriculture, Forest Service, Intermountain Region.

II. DETERIORATION OF FIRE-KILLED CONIFERS

The previous paper, "Post-Fire Tree Survivability and Insect Interactions", discusses factors affecting mortality of fire-damaged trees. This paper is meant to address changes that occur within a tree once it dies. A third paper, "Tree Deterioration and Fungal Associates of Fire-Killed Conifers: An Annotated Bibliography", follows this paper.

Much of the work done prior to 1990 on deterioration of fire-killed timber has been adequately reviewed and summarized by Lowell and others (1992). Their paper is attached as an appendix for reference. This paper summarizes general information on deterioration and specifically summarizes the five year study done by Hadfield and Magelssen (1996-2000). Their study is the most current and regionally specific information available on deterioration of the common conifer species found in the Northern Rockies.

Deterioration of dead trees is caused mainly by fungi, insects (both directly and indirectly by vectoring in fungi), and weathering. The three most common deteriorations are blue stain (aka sap stain), decay and weather checking.

Blue Stain/Sap Stain

Blue stain is discoloration in sapwood of dead trees caused by non-decaying fungi. Heartwood is usually unaffected. These fungi derive their nourishment from food materials stored in cells of the sapwood. They do not usually deteriorate the cell walls of wood; penetration of wood cells usually occurs through the pits of the cell walls, and is mostly a mechanical action, rather than an enzymatic action, such as found in decay fungi (Panshin and de Zeeuw 1980).

The spores of blue staining fungi are very sticky which makes them well adapted for insect dispersal and very poorly adapted for wind dissemination. Blue stains are generally vectored into trees by bark beetles, and to a lesser degree, other subcortical insects (Harrington 1993).

Some tree species are more susceptible to blue stain than others. Sapwood of pines is often completely blue stained within a year after death, while Douglas-fir often has limited blue stain after death. In eastern Washington, Douglas-fir was minimally stained after 2 years, and after 5 years was still only 12-16% stained (% total cubic foot volume). Lodgepole pine and ponderosa pine were >36% and >24% stained at one-year dead, respectively, which represents nearly all the sapwood in these trees (Hadfield and Magelssen 1996).

Decays

Decays are caused by fungi that break down wood cells by enzymatic action, thus causing significant loss of wood strength (Panshin and de Zeeuw 1980). There are several groups of fungi responsible for decay in dead trees. In general, white rotters are the first to move into a dead tree, followed by brown rotters. There is limited evidence indicating blue stain may be a precursor to these decay fungi. White rot fungi break down lignin and cellulose and leave behind a whitish or bleached color in the wood. Brown rotters break down cellulose and hemicellulose, leaving lignin unaffected, and leave behind a brownish or reddish color in the wood. Spores of these fungi enter trees through openings. They are often vectored by bark beetles and wood borers (Borden and McClark 1970; Castello et al. 1976).

Decays can affect sapwood or heartwood of trees. While the tree is alive, sapwood is very resistant to decay and heartwood is susceptible to decay from a small group of fungi. Dead sapwood in all tree species is susceptible to decay and is the first part of the tree degraded after trees die. Trees with large proportions of sapwood such as found in young, fast growing trees, experience greater amounts of sapwood decay, than older, slower growing trees of the same size. In the short term (five years or less), heartwood decay present in trees prior to death contributes very little to deterioration after the tree dies (Thomas and Craig 1958).

Three of the most common decay fungi found in fire-killed conifers are *Cryptoporus volvatus* ((Peck) Shear (=*Polyporus volvatus* Peck)), *Fomitopsis pinicola* ((Sw.:Fr.) P. Karst (=*Fomes pinicola* (Sw.:Fr.) Cooke)), and *Trichaptum abietinum* ((Dickson:Fr.) Ryvarden (=*Polyporus abietinus* (Dickson:Fr.) Donk)). *C. volvatus* is a white rotter, principally found in the sapwood. *F. pinicola* is a brown rotter which decays both the sapwood and heartwood. *T. abietinus* is a very common and prolific white rotter of dead conifers, and readily decays the sapwood.

Weather Checking

When trees begin to dry out after death they lose moisture, shrink and develop cracks. These cracks are also referred to as weather checks, or checks. Weather checking is often most common in upper boles of trees, and on hot, dry, or windy sites. These cracks can be entry points for decay fungi, but once trees slough off their bark, they often become too dry for fungi to be successful. Cracks also reduce the strength of affected wood.

Rate of Deterioration

There are many factors that affect the rate of deterioration of trees. These include width of growth rings, size and age of trees, sapwood thickness, bark thickness, and environmental factors of the site (Kimmey and Furniss 1943). Individual trees with thick sapwood deteriorate more rapidly than those with thin sapwood, although heartwood ring width may be more important than sapwood thickness in influencing the rate of decay. Younger, faster growing trees deteriorate faster because of their wider growth rings. Large, old trees not only have proportionately thinner sapwood, but they also have a band of wood with tight growth rings; both factors result in a slower deterioration in older trees (Kimmey 1955). A tree larger than another due to a fast growth rate may actually deteriorate faster because wider growth rings will allow faster penetration by insects and fungi. In general, large trees deteriorate more slowly than small trees only when difference in size is largely a result of difference in age.

Regarding environmental factors of a site, dry windy sites tend to have slower decay rates due to trees drying out quickly, making them less habitable by decay fungi. Larger, thick-barked trees may be among the first to decay, and thin-barked trees may be the surviving remnants. This trend also holds true within a tree; the upper bole of trees dry out quicker so are less affected by decay fungi than the lower bole, where bark is thicker and moisture is retained. Hadfield and Magelssen (1996-2000) found that decay was concentrated in the lower bole of most tree species. The upper boles have thinner bark and dry out faster. Decay fungi will not grow at wood moisture content of less than 20 percent (Graham 1962). Although the upper portions of boles are less likely to decay, they are the most likely to suffer from weather checking due to a faster rate of drying (Lowell and Cahill 1996). Rates and amounts of decay are also somewhat dependent on the level of infestation by their vectors (Thomas and Craig 1958). Many of the decay fungi are carried into trees when insects, principally bark beetles and wood borers, attack injured trees (Borden and McClark 1970; Castello et al. 1976). Borden and McClark (1970) found the occurrence and density of *C. volvatus* in fire-killed Douglas-fir to be strongly dependent on attacks by Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins). *C. volvatus* was found in fire-killed Douglas-fir with woodborer attacks, but at a much lower incidence than in trees with Douglas-fir beetle attacks (34% and 100% incidence, respectively).

Deterioration of Common Conifer Species in the Northern Rockies

Hadfield and Magelssen (1996-2000) established a study in eastern Washington in 1994 to measure wood changes in trees killed by fires. The fires occurred in July and August 1994 on the Colville, Okanogan, and Wenatchee National Forests. Seven tree species were included in the study: Douglas-fir, grand fir, subalpine fir, western larch, lodgepole pine, ponderosa pine, and Engelmann spruce. Trees were cut down and examined annually over five years. Most of the data in the following text and tables came from this study; other data has been added and credited as appropriate.

Douglas-fir: Damage to Douglas-fir during the first year after death is limited to minimal amounts of stain in the outer sapwood, and weather checking. Weather checking will be more severe in younger thinner-barked trees, and trees on hot, windy sites. Hadfield and Magelssen (1996) found weather checking to be most significant midbole on trees. Nearly all trees will be attacked by woodborers in the first year.

By end of year two, nearly all trees will have sapwood staining, with less than 10% cubic foot volume affected. About half the trees will have saprot, but with minimal cubic foot volume affected. Pouch fungus (*C. volvatus*) is common on trees at year two. All trees will likely be attacked by woodborers by end of year two. Most trees will be cracked, and cracks will be most common and deepest at midbole. Most trees will still retain their bark.

At end of year three, total cubic foot volume affected by staining will increase to almost 23% (Hadfield and Magelssen 1998). Nearly 75% of trees may experience saprot, but cubic foot volume affected will still be minimal. Old pouch fungus conks are common after three years. Fruiting bodies of the red belt fungus (*F. pinicola)* may begin to appear. Most trees should still retain bark with very little sloughing.

After four years, saprot will increase, but cubic foot volume affected will likely still be low. Dead pouch fungus conks will be common, and fruiting bodies of the red belt fungus will increase. Trees will still retain most of their bark. Around year four, trees begin to break off and fall.

At end of five years, tree fall increases and down trees may already be 100% decayed. Lower volumes of decay are found in larger, slower growing trees on higher elevations. Tree breakage below crown will be common. All trees will have some level of decay, and decay will be greatest in lower portion of stem. Bark will still be mostly retained.

DOUGLAS-FIR[1]

Damage	**Number of years after fire-kill**				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	3	9	22	18	12
% Cubic volume decayed	0	2	5.4	6.6	16.6
% Cubic vol. w/cracks	<1[2]	<10[2]	33.3	31.8	40.3
Annual fall down rate	0	0	0	7.5%	15.8%

[1] Average dbh ranged from 11.7” to 20.6”

[2] Data are % total cubic volume loss from Lowell and Cahill (1996), otherwise data from Hadfield and Magelssen (1996-2000).

Grand fir: Damage to grand fir during the first year after death includes appreciable amounts of staining. Most trees have saprot in the lower log, but very little volume is affected the first year. Nearly all trees are weather checked during the first year, but very little volume is affected. Woodborer attacks are common.

Nearly all trees will have saprot at end of year two, but volume affected will still be minimal and most common in lowest log. All trees will likely be attacked by woodborers, and all trees will likely have cracks. Fir engraver (*Scolytus ventralis* LeConte) attacks will be very common, with 80% being attacked and producing successful broods in eastern Washington (Hadfield and Magelssen 1997). An occasional tree may fall.

At end of year three, percent cubic foot volume stained increases, and most trees will have extensive bark sloughing. Tree fall will likely still be minimal.

The most significant changes from year three to year four are the substantial increase in decay and subsequent increase in tree fall.

At end of year five, tree breakage is common due to decay. Staining will decrease in a large percentage of trees because the stained wood will now be decayed. All trees will have some level of decay, and it will be most common and greatest in lowest log. All fallen trees will likely be 100% decayed.

GRAND FIR[1]

Damage	**Number of years after fire-kill**				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	10.9	9	22	38	9.5
% Cubic volume decayed	0.4	2.4	6.6	18.7	39.7
% Cubic vol. w/cracks	<5[2]	<10[2]	52.5	49.6	30.4
Annual fall down rate	0	1.3%	1.3%	10.4%	21.7%

[1] Average dbh ranged from 13.6” to 17.8”

[2] Data are % total cubic volume loss from Lowell and Cahill (1996), otherwise data from Hadfield and Magelssen (1996-2000).

Subalpine fir: Nearly all subalpine fir is stained during the first year, but the stain is limited to the outer sapwood. Very little saprot moves into the tree, but nearly all trees will start to weather check. Attack by woodborers is low, and more common on trees with low to moderate burn intensity.

The only appreciable change from year one to year two is the increase in weather checking, which increases at all positions within the trees.

The biggest change from year two to year three is the extensive loss of bark on most trees.

There is no appreciable change from year three to year four.

At end of year five, tree fall will still be negligible. All trees will have stain, but very small volume affected. Although a great percentage of trees will have some level of decay, it will affect a small volume and will be confined to the butt. All trees will have deep weather checks, and less than 50% of trees may be infested with insects.

SUBALPINE FIR[1]

Damage	**Number of years after fire-kill**				
	1	2	3	4	5
% Cubic volume stained	6	4.9	6.3	6.4	5.5
% Cubic volume decayed	0.1	<1	<1	1.3	5.0
% Cubic vol. w/cracks	<5[2]	<10[2]	68.7	65.2	68.4
Annual fall down rate	0	0	0	0	0

[1] Average dbh ranged from 11.5” to 13.8”

[2] Data are % total cubic volume loss from Lowell and Cahill (1996), otherwise data from Hadfield and Magelssen (1996-2000).

Western larch: Nearly all western larch is stained within the first year, but it is limited to the outer sapwood. There is very minimal saprot. Most, if not all trees, will be attacked by woodborers.

At year two, cubic foot volume affected by stain increases from less than 6% to almost 21% (Hadfield and Magelssen 1997). Trees will still have negligible amounts of saprot. All trees will likely crack at most positions on the boles. Bark will still hold on tight.

At end of year three, saprot will still be negligible. All trees will likely crack at most positions on the bole, and greater than 50% of cubic volume may be affected. Bark loss should still be negligible.

At end of year four, the most significant change is the increase in cubic foot volume affected by cracks. Up to 80% of volume may be affected.

At year five, tree fall will still be negligible. Most of the sapwood in all trees will be stained, and there may be a trace of saprot. Most, if not all, trees will have weather checks and infestations by woodborers. Bark loss will be negligible.

WESTERN LARCH[1]

Damage	**Number of years after fire-kill**				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	5.7	20.9	23.7	23.1	21.9
% Cubic volume decayed	0.01	0	<1	0	<1
% Cubic vol. w/cracks			56.2	78.6	80.3
Annual fall down rate	0	0	0	0	0

[1]Average dbh ranged from 9.9” to 15.4”; Data from Hadfield and Magelssen 1996-2000.

Lodgepole pine: All trees will have stain affecting most of the sapwood volume within the first year, and very little saprot will occur. About half of trees will crack, but cracks will likely be confined to lowest log. Woodborer attacks will likely be low.

The only appreciable change from year one to year two is the increase in cracking and the beginning of tree fall. All trees will likely have cracks. Majority of trees may be attacked by woodborers, but at a low intensity (Hadfield and Magelssen 1997).

The only noteworthy change from year two to year three is that bark loss from bases of trees may become common. Weather checking may affect over 60% of cubic foot volume.

There is very little change from year three to year four.

Very few trees will fall over in 5 years. All trees will have stain affecting most of the sapwood. There will be very little saprot, and what is there will be mainly in lowest log. All trees will likely have weather checks. Bark loss at base of trees will be common.

Other studies indicate that lodgepole pine tree fall may be nearly 50% within five years after fire, with most tree falling occurring in smaller diameters (Lyons 1977).

LODGEPOLE PINE[1]

Damage	**Number of years after fire-kill**				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	36.2	41.3	53.8	49.6	47.2
% Cubic volume decayed	0.01	<1	<1	<1	<1
% Cubic vol. w/cracks			62.4	65.2	64.8
Annual fall down rate	0	2.5%	0	0	0

[1] Average dbh ranged from 8.4” to 14.4”; Data from Hadfield and Magelssen 1996-2000.

Ponderosa pine: Nearly all sapwood is stained at end of year one. Very little saprot will be present and very few trees will have cracks. Majority of trees will be attacked by woodborers.

At end of year two, pouch fungus fruiting bodies will be common. Nearly all sapwood in all trees now stained, and decay will start in many trees. About half of trees can be expected to crack, and all trees will likely be attacked by woodborers.

At end of year three, staining will be at its peak, affecting over 75% of cubic foot volume (Hadfield and Magelssen 1998). Trees begin to fall due to decay in lowest log. Bark is still mostly retained.

Tree fall increases substantially from year three to year four. Trees tend to break off close to the ground where decay is greatest. Bark sloughing is still minimal.

Nearly half of the trees may break close to the ground between years 4 and 5. Most trees will have extensive decay, but volume decayed may be highly variable. All trees will likely have weather checks and woodborers. Bark loss will still be negligible.

Other studies indicate similar fall rates for ponderosa pine (Harrington 1996). Second growth ponderosa pine decays very rapidly near the ground and readily breaks off. There is evidence that ponderosa pine with resin hardened bases, like those found on old growth ponderosa pine, may stand for many years after being killed (Keene 1955).

PONDEROSA PINE[1]

Damage	**Number of years after fire-kill**				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	24.3	48.7	75.4	59.3	17.2
% Cubic volume decayed	0.2	4.2	3.4	20	76
% Cubic vol. w/cracks	<2[2]	<10[2]	30.0	43.2	17.8
Annual fall down rate	0	0	6.7%	20%	53%

[1] Average dbh ranged from 13.8" to 14.9".

[2] Data are % total cubic volume loss from Lowell and Cahill (1996), otherwise data from Hadfield and Magelssen (1996-2000).

Engelmann spruce: In year one, all trees will have some stain, most associated with ambrosia beetle attacks. Negligible saprot will occur, and majority of trees will have cracks and ambrosia beetle attacks.

At end of year two, saprot will be common, but volume affected will be minimal and limited to the lowest log. All trees will crack, and low intensity woodborer attacks may be common. Ambrosia beetle attacks common at midbole. An occasional tree may fall.

At end of year three, saprot volume will still be minimal. Tree fall may occur during year three, but will likely be very low. Cracks may begin to affect almost half of cubic foot volume. Much bark will slough, especially from lower bole.

Very few trees will fall or break over 5 years. All trees will have sap stain, mostly associated with ambrosia beetles. As much as half of the trees will have saprot, but it will likely be confined to the bottom log and associated with cracks. The percent volume decayed will be very low. All trees will likely have weather checks. Woodborers and ambrosia beetles will be common. Ambrosia beetle galleries may be most frequent at midbole. Most trees will lose most of their bark, mostly in the lower bole.

Other studies indicate standing spruce trees deteriorate very slowly, and snags may stand intact for decades (Mielke 1950).

ENGELMANN SPRUCE[1]

Damage	Number of years after fire-kill				
	1	2	3	4	5
% Cubic volume stained	12.9	20.4	19.3	23.5	30.7
% Cubic volume decayed	<1	<1	<1	<1	6.4
% Cubic vol. w/cracks			44.8	53.4	57.1
Annual fall down rate	0	1.3%	1.7%	2.6%	0

[1] Average dbh ranged from 15.0” to 19.1”; Data from Hadfield and Magelssen 1996-2000.

Summary

All fire-killed trees experience some level of deterioration after five years. Woodborers are the primary insect attacking dead trees, with attacks beginning within the first year. By the end of the second year, most of the sapwood in trees of all species will be stained. Many trees start cracking in the first year, with subalpine fir cracking the most in year one. Decay is virtually nonexistent in the first year, but becomes common in the second year, with minimal volume affected. In general, second growth ponderosa pine will have the most breaks and falls over the first five year period. Grand fir will also experience substantial breakage and fall. In general, there will be low levels of decay in western larch, subalpine fir, and Engelmann spruce due to high rates of cracking and drying out. In all trees, decay will be most common in the lowest log where moisture is retained.

List of References

Borden, J.H.; McClark, M. 1970. Biology of *Cryptoporus volvatus* (Peck) Shear (*Agaricales polyporaceae*) in southwestern British Columbia: Distribution, host species, and relationship with subcortical insects. SYESIS 3: 145-154.

Castello, J.D.; Shaw, C.G.; Furniss, M.M. 1976. Isolation of *Cryptoporus volvatus* and *Fomes pinicola* from *Dendroctonus pseudotsugae*. Phytopathology 66:1431-1434.

Graham, D.P. 1962. What is known about disease potential of wind-thrown timber; A summary report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 8 p.

Hadfield, J.S.; Magelssen, R.W. 1996. Wood changes in fire-killed eastern Washington tree species- first year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 25 p.

------------1997. Wood changes in fire-killed eastern Washington tree species- second year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 35 p.

------------1998. Wood changes in fire-killed eastern Washington tree species- third year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 37 p.

------------1999. Wood changes in fire-killed eastern Washington tree species- fourth year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 35 p.

------------2000. Wood changes in fire-killed eastern Washington tree species- fifth year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 34 p.

Harrington, M.G. 1996. Fall rates of prescribed fire-killed ponderosa pine. INT-RP-489. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station 7 p.

Harrington, T.C. 1993. Biology and taxonomy of fungi associated with bark beetles. IN: Schowalter, T.D.; Filip, G.M., eds. Beetle-Pathogen Interactions in Conifer Forests. Academic Press: 37-42.

Keen, F.P. 1955. The rate of natural falling of beetle-killed ponderosa pine snags. Journal of Forestry 53: 720-724.

Kimmey, J.W. 1955. Rate of deterioration of fire-killed timber in California. Circular No. 962. Washington, DC: U.S. Department of Agriculture. 22 p.

Kimmey, J.W.; Furniss, R.L. 1943. Deterioration of fire-killed Douglas-fir. Tech. Bull 851. Washington, DC: U.S. Department of Agriculture. 61 p.

Lowell, E.C.; Cahill, J.M. 1996. Deterioration of fire-killed timber in southern Oregon and northern California. Western Journal of Applied Forestry 11: 125-131.

Lowell, E.C.; Willits, S.A.; Krahmer, R.L. 1992. Deterioration of fire-killed and fire-damaged timber in the Western United States. Gen. Tech. Rpt. PNW-292. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 27 p.

Lyon, L.J. 1977. Attrition of lodgepole pine snags on the sleeping child burn, MT. Research Note INT-219. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Mielke, J.L. 1950. Rate of deterioration of beetle-killed Engelmann spruce. Journal of Forestry. December: 882-888.

Panshin, A.J.; de Zeeuw, C. 1980. Textbook of Wood Technology; Structure, identification, properties, and uses of the commercial woods of the United States and Canada. 4th Edition. McGraw-Hill Book Co., Inc. New York. 374-376.

Thomas. G.P.; Craig, H.M. 1958. Deterioration by fungi of killed Douglas-fir in Interior British Columbia. Ottawa, Canada.: Department of Agriculture, Science Service, Forest Biology Division. 20 p.

III. TREE DETERIORATION AND FUNGAL ASSOCIATES OF FIRE-KILLED CONIFERS: AN ANNOTATED BIBLIOGRAPHY

Deterioration of Fire-killed and Fire-damaged Trees

Boyce, 1961. Forest Pathology. McGraw-Hill Book Co., Inc. New York. 572 p.

> The direct loss due to burn is seldom more than 3% of the gross volume. Insect infestation and blue-staining of sapwood begin the first year following fire. After 3 years, the sapwood is no longer merchantable because of insect boring and decay by fungi, including *Fomes pinicola and Polyporus abietinus* (syn. *Trichaptum abietinum*, see “Common Tree Diseases of British Columbia”, 1996)

Hadfield, J.S.; Magelssen, R.W. 1996. Wood changes in fire-killed eastern Washington tree species- first year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 25 p.

------------1997. Wood changes in fire-killed eastern Washington tree species- second year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 35 p.

------------1998. Wood changes in fire-killed eastern Washington tree species- third year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 37 p.

------------1999. Wood changes in fire-killed eastern Washington tree species- fourth year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 35 p.

------------2000. Wood changes in fire-killed eastern Washington tree species- fifth year progress report. Wenatchee, WA: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, Wenatchee Service Center. 34 p.

This series of reports summarized wood changes in fire-killed trees in eastern Washington at annual increments for 5 years. Tree species studied were Douglas-fir, grand fir, subalpine fir, western larch, lodgepole pine, ponderosa pine, & Engelmann spruce. Out of all the studies done on deterioration of fire-killed trees, this is probably the most applicable to the dryer parts of western Montana (including Missoula and Bitterroot Counties) and Central and Eastern Montana, because of the similarity in climate and tree species.

General observations and Conclusions. All fire-killed trees experienced some level of deterioration after 5 years, with all trees having been affected by fungi, insects, and abiotic agents. Woodborers were the primary insect attacking the dead trees, and the attacks began within the first year. By the end of the second year, most of the sapwood in trees of all species was stained. Many trees started cracking in the first year, with subalpine fir showing the most cracks in year one. Decay was virtually nonexistent the first year, but conks of decay fungi, primarily *C. volvatus*, were very common in grand fir, Douglas-fir and ponderosa pine in year two. Ponderosa pine was the species that had the most breaks and tree falls, with grand fir also experiencing substantial breakage. The rate of breakage in Douglas-fir increased substantially between years three and four. Low levels of decay in western larch, subalpine fir, lodgepole pine, and Engelmann spruce may be directly related to the high amount of cracking that occurred. It has been written in other places that cracking causes wood to dry out quickly and thusly, fungal growth is inhibited. In trees with decay, it was more common in lower logs.

Cracking: After 4 years, the ranking of species from those with the most volume affected by cracks to those with the least was as follows: western larch (80%), lodgepole pine (66%), subalpine fir (66%), Engelmann spruce (55%), grand fir (50%), ponderosa pine (43%), and Douglas-fir (31%).

Pouch fungus. There was a large increase in the fruiting of *C. volvatus* between year one and year two. Almost all of the conks were found on Douglas-fir, grand fir, and ponderosa pine. After year 3, 66 percent of the Douglas-fir had conks, 33 percent of the grand fir, and 47% of the ponderosa pine. Visible sap rot was not always evident at the point of fruiting body production.

Fomitopsis pinicola. First fruiting body of red belt was found in year 3 on a Douglas-fir. Although this was the first year a fruiting body was found, red belt is thought to be the predominant cause of the decay throughout the study area. By year 4, fruiting bodies of *F. pinicola* were becoming more common and conks of *Trichaptum abietinum* were first seen. Fruiting bodies of both fungi were only seen on Douglas-fir. In year 5, a fruiting body of *Gloeophyllum sepiarium* was first seen on Douglas-fir.

Summary by species

Douglas-fir

	Number of years after fire-kill

	1	2	3	4	5
% Cubic volume stained	**3**	**9**	**22**	**16**	**12**
% Cubic volume decayed	**0**	**2**	**5.4**	**6.6**	**16.6**

Summary at year 5:

Trees that fell were now 100% decayed. Authors noticed lower volume of decay in larger, slower growing trees on the highest elevation. Greater than 25% of trees broke below crown. Approximately 25% of trees no longer had sap stain because stained wood now decayed. In trees with stain, 12% cubic volume affected. All trees had some level of decay. Decay greatest in lower portion of stems. All trees had cracks, location of most cracks and deepest cracks was midbole. All had been attacked by woodborers. The bark was mostly still retained.

Grand fir

	Number of years after fire-killl				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	**12**	**9**	**22**	**38**	**9.5**
% Cubic volume decayed	**0.4**	**2.4**	**6.6**	**18.7**	**39.7**

Summary at year 5:

Natural breakage was common due to decay. Thirty-five percent of trees did not have stain, because the stained wood was now decayed. All trees had decay, and it was most common and greatest in lowest log. All fallen trees were 100% decayed. All trees had been attacked by woodborers, and all trees had weather checking (most happened by year 2). Most trees had extensive bark sloughing.

Subalpine fir

	Number of years after fire-kill				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	**6**	**4.9**	**6.3**	**6.4**	**5.5**
% Cubic volume decayed	**0.1**	**<1**	**<1**	**1.3**	**5.0**

Summary at year 5:

There was no natural fall over the five years. All trees had stain, but very small volume affected. **Seventy-five percent of trees had decay, affecting a small volume and confined to the butt**. All trees had deep weather checks, and less than 50% of trees were infested with insects.

Western larch

	Number of years after fire-kill

	1	2	3	4	5
% Cubic volume stained	**5.7**	**20.9**	**23.7**	**23.1**	**21.9**
% Cubic volume decayed	0.01	**0**	**<1**	**0**	**<1**

Summary at year 5:

No trees fell over 5 years. Most of the sapwood in all trees was stained, and there was only a trace of sap rot. All trees had weather checks affecting 80% of the volume, and all trees were infested by woodborers. There was almost no bark loss.

Lodgepole pine

	Number of years after fire-kill				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	**36.2**	**41.3**	**53.8**	**49.6**	**47.2**
% Cubic volume decayed	**0.01**	**<1**	**<1**	**<1**	**<1**

Summary at year 5:

Two trees fell over in the 5 years, both occurred in year 2. All trees had stain affecting most of the sapwood. **There was very little sap rot, and what was there was mainly in lowest log**. All trees had weather checks, and all had borers, but in small numbers. Bark loss at base of trees was common.

Ponderosa pine

	Number of years after fire-kill				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	**24.3**	**48.7**	**75.4**	**59.3**	**17.2**
% Cubic volume decayed	**0.2**	**4.2**	**3.4**	**20**	**76**

Summary at year 5:

Nearly half of the trees (45%) broke close to the ground between years 4 and 5. Nearly all sapwood stained. Ninety percent of trees had decay, but volume decayed was highly variable, with an average of 76%. All trees had weather checks, and all trees had borers. There was no bark loss.

Engelmann spruce

	Number of years after fire-kill				
	1	**2**	**3**	**4**	**5**
% Cubic volume stained	**12.9**	**20.4**	**19.3**	**23.5**	**30.7**
% Cubic volume decayed	**negl**	**negl**	**<1**	**<1**	**6.4**

Summary at year 5:

Very few trees fell or broke over 5 years. All had sap stain, mostly associated with ambrosia beetles. Approximately half of the trees had sap rot, confined mostly to the bottom log and associated with cracks. The percent volume decayed was very low (6.4%). All trees had weather checks. Only one conk (*C. volvatus*?) was seen over 5 years (100 trees). Almost all trees had borers but in small numbers. Ambrosia beetle galleries were in more than 50% of the trees, most frequently at midbole. Most trees had lost most of their bark, mostly in the lower bole.

Kimmey, J.W. 1955. Rate of deterioration of fire-killed timber in California. Circular No. 962. Washington, DC: U.S. Department of Agriculture. 22 p.

Kimmey studied deterioration rates of white fir, Douglas-fir, sugar pine, ponderosa pine and Jeffrey pine from burned areas in northern and central California. The age of the burns ranged from 0 to 17 years. My review will cover general findings and present specific results only for Douglas-fir, and ponderosa pine because these species occur in the Northern Region.

Stain. Kimmey found blue-stain to be much less of a problem in Douglas-fir than in the pines; out of six fungi commonly found in Douglas-fir sapwood, blue-staining fungi were the least predominant. In ponderosa pine, it was the most predominant sapwood inhabiting fungus. Significant proportions of Douglas-fir sapwood were not lost to blue-stain in this study. Conversely, in ponderosa pine, a quarter of the sapwood cubic-foot volume was blue-stained after one year, and nearly 100% was blue-stained after two years.

Wood decay. *Fomes pinicola* was the most prolific decayer of both sapwood and heartwood of all tree species studied. *Polyporus volvatus (*syn*. Cryptoporus volvatus)* and *P. abietinus* were the second and third most important decay fungi, but were limited to only decaying sapwood. *Fomes officinalis and Poria albipellucida* (syn. *Ceriporiopsis rivulosa* (Berk. & Curtis) Gilb. & Ryvarden - - (see common tree diseases of British Columbia 1996 for that authority) were also found decaying the heartwood of Douglas-fir, but were considered minor. Observations in this study supported findings of Kimmey and Furniss (1943) that the heartwood of fast-growing trees with wide growth rings decays faster than slow-growing trees with tight rings.

Stand break-up. In the first two years there is little stand break-up. By the third year, trees 10-12 inches of the species with thick sapwood begin to break at ground level and at various heights along the bole. By the fourth and fifth year, many of the small ponderosa pine will have fallen and even some large trees. Some small Douglas-fir also begin to fall. After the fifth year, stand break-up accelerates with ponderosa pine being one of the first to drop out of the dead stand. Tops start falling out of large diameter trees in about 8-10 years. The last remnants of the fire-killed stand are large diameter stubs of Douglas-fir and ponderosa pine, unless the stand includes a more decay-resistant tree species, "such as incense-cedar" (replace this with western larch and redcedar for our area??). At high elevations, because of the prevalence of thin barked species, and on very dry sites, the break-up pattern may be different because decay rates are arrested when wood dries out. Where lack of moisture limits decay, the larger, thick-barked trees may be among the first to drop out and the smaller, thin-barked trees may be the surviving remnants.

Deterioration by Species

Douglas-fir. The sapwood was fully decayed by the end of the third year. He summarizes that heartwood rate is similar to that found by Kimmey and Furniss (1943). Big difference between Kimmey's California study and the 1943 study was that there was very little blue stain found in the California trees. (perhaps this was due to low Doug-fir beetle populations in the area???). Therefore, in the following table, "deterioration speaks to sapwood and heartwood decay and not just discoloration from blue-stain. The following table was pulled from Fig. 4A, p.13.

DBH (inches)	Percent cubic-foot volume lost by number of years after burn		
	1-3 yrs	4-6 yrs	7-10 yrs
10-20	43-37	62-51	68-57
21-30	33-27	53-41	55-47
31-40	26-22	40-35	47-40
41-50	22-16	34-29	40-36
50+	15-12	27-20	40-34

Ponderosa pine. At the end of the first year there was no appreciable decay of the sapwood, but ¼ of the cubic volume was blue-stained. By year 2, extensive deterioration of the sapwood was evident, and nearly 100% of the sapwood volume was blue-stained. By year 3, sapwood was generally decayed, although some might still be salvable. Heartwood decay did not become evident until year 3. The following table was pulled from Fig. 6A, p16.

DBH (inches)	Percent cubic-foot volume lost by number of years after burn.			
	1 year	2 years	3-4 yrs	5-6 yrs
10-20	blue stain	52-47	91-82	98-91
21-30	blue stain	45-41	79-73	90-86
31-40	blue stain	40-36	72-66	86-82
41-50	blue stain	81-32	65-59	82-77
50+	blue stain	32-26	58-47	77-72.

Kimmey, J.W.; Furniss, R.L. 1943. Deterioration of fire-killed Douglas-fir. Tech. Bull 851. Washington, DC: U.S. Department of Agriculture. 61 p.

This study looked at deterioration of fire-killed Douglas-fir on forests of the Coast Range and Cascade Range in southwest Washington and western Oregon. For applicability to conditions in 2000 in most of the Northern Region, attempts will be made to weed out data specific to sampling done in the “young growth” which, for this study, included trees 60 – 250 yrs old and a dbh range of 10 – 50 inches**.** Some generalities will be presented that are not necessarily limited to that tree class.

The agents causing deterioration of fire-killed trees are fungi, insects, and weather, with the latter two being the most important. Insects and fungi often work together, and conditions that favor decay often also favor insects. Sometimes, insects follow decay, and in others, the insects precede decay. In this study they considered their effects in combination rather than separately. Factors that influence the rate of deterioration include wood character, width of growth rings, size and age of trees, sapwood thickness, and environmental factors of the site.

Stain. Blue-stain fungi attack sapwood exclusively. They are primarily active for the first 3 years after fire-kill. Stain fungi do not materially weaken the wood, but the discoloration usually leads to mill degrade.

Insect associates. The Douglas-fir beetle is by far the most important beetle to infest the phloem region, and is known to introduce blue-staining fungi and *C. volvatus*, which eventually can cause sapwood decay. Some species of flatheaded and roundheaded borers may also feed in the phloem, but are of minor importance. The sapwood of fir-killed trees is commonly infested by a wide variety of borers, but they usually do not become abundant enough to directly cause cull before fungi have rendered the wood unusable. Ambrosia beetles, flatheaded borers, roundheaded borers, and horntails are all examples of insects that may infest the sapwood in the first few years after a fire. There are a few different roundheaded borers, which are reported to infest the heartwood and occasionally cause salvage problems. One of these is the “timber worm” (*Ergates spiculatus* Lec.), which will often continue to attack as long as sound wood remains. The timber worm usually does not become abundant until 5 to 6 years following fire. Another roundheaded borer that can cause substantial damage to heartwood is *Criocephalus productus* Lec.. The principal damage is caused by the construction of the pupal cells which takes place 3 to 6 years following fire.

Sap rot and general decay. They did not find *C. volvatus* to be responsible for much sapwood decay, but they did find it was responsible for “brashness” and discoloration of the sapwood. Principle sapwood decayers were *Fomes pinicola* (syn. *Fomitopsis pinicola*) and *Polyporus abietinus* (syn. *Trichaptum abietinum*). *P abietinus* only caused decay in the sapwood, where it was found to cause 50% of the decay. *F. pinicola* was an important rotter of both sapwood and heartwood; it caused nearly 50% of the sapwood decay and more than 75% of the heartwood decay. Other fungi commonly found to cause considerable decay in both the sapwood and heartwood included *Fomes officinalis* (syn. *Fomitopsis officinalis* (Villars.:Fr.) Bondartsev & Singer) and *Lenzites saepiaria* (syn. *Gleophyllum separium* (Wulfen.:Fr.) P.Karst).

Deterioration Rates. They do not break out different rates of loss by stain, sapwood decay, etc., they just describe "general deterioration" which basically lumps it all together. Individual trees with thick sapwood deteriorated more rapidly than those with thin sapwood, largely because insects and fungi penetrated the heartwood more rapidly beneath thick sapwood than beneath thin sapwood. The reason for this difference may be due to the thick sapwood holding moisture well and providing a favorable environment for the establishment of fungi and insects. Their data found that sapwood thickness remains fairly constant throughout the life of Douglas-fir. Average sapwood thickness of young-growth trees was 1.5 inches; for intermediate-growth (200-400 years old), 1.6 inches; and for old-growth (400 years+), 1.7 inches. Therefore, the *amount* of sapwood stain and rot in all age and diameter classes of Douglas will be similar, but the proportional volume lost will be greater in smaller trees because of less volume represented by heartwood. Heartwood ring width may be more important than sapwood thickness in influencing the rate of decay. Younger, faster growing trees may deteriorate faster because of their wider growth rings. Large, old, trees not only have proportionately thinner sapwood, but they also have a band of wood with tight growth rings; both factors result in a slower deterioration in the older trees. They also suggest that a tree larger than another just because it grew faster, may actually deteriorate faster because the wider growth rings will allow faster penetration by insects and fungi. They concluded that, in general, large trees deteriorate more slowly than small trees only when the difference in size is largely a result of difference in age. That being said they still found that within their "young-growth" class, smaller trees deteriorated faster than larger ones (this table has calculated weighted averages for data presented in Table 9, p.56 – "young-growth" only):

DBH (inches)	Percent cubic-foot volume lost by number of years after burn		
	1-3 yrs	4-6 yrs	7-9 yrs
11-20	65.3	72.1	100
21-30	27.6	57.4	66.6
31-40	24.5	60.4	46.8
41-50	19.48	67.2	
51-60	19.2		

In their "Summary and Conclusions" they make a general statement that the "young-growth" experienced fifty percent deterioration in 3 to 4 years.

Littke, W.R.; Gara, R.I. 1986. Decay of fire-damaged lodgepole pine in south-central Oregon. Forest Ecology and Management. 17: 279-287.

Study done on LPP in south-central Oregon that had survived fires that occurred over a period from 1839 to 1982). There were two groups of sample trees, those with no visible above-ground fire damage, and those with basal wounds or scars from fire. Tree roots were excavated, and then trees were sectioned. Results: Heartrot columns not established directly through fire wounds on bole. Fire damaged roots were the infection sites for heartrot fungi to get into the bole of trees. Approximately 70% of fire-scarred trees had root damage, which invariably were decayed. Trees with fire damaged roots were significantly more likely to have butt rot than trees with undamaged roots.

Butt rot:	No butt rot	
24	4	trees with fire damaged roots
6	15	trees without damaged roots

Recent fire damaged tissue was found to be infected with non-decay fungi and white rotters, while advanced decay was caused by brown rot basidiomycetes. *Pholiota carbonicola* (white rotter) was the primary invader of freshly scorched LPP roots. *P. carbonicola* is known to fruit gregariously following fires in conifer stands. A mixture of white- and brown- rotters were found in roots damage 6+ years prior, these were *Poria subacida*, *Heterobasidion annosum*, *Lentinus lepideus*, and *Sistorema brinkmannii*. In very old damaged trees, isolations were made from resultant heartrot columns, and the fungi were: *Poria asiatica, Gloeophyllum odoratum, Tyromyces sericeomollis (leucospongia*?) and others. Decay did not progress at a constant rate, the rate increased over time. *P. asiatica* most significant brown rotter in heart rot columns. Infected trees grew slower than uninfected trees and were preferentially selected by dispersing MPB. The number and distribution of infected trees is related to the subsequent magnitude of MPB outbreaks.

Lowell, E.C.; Willits, S.A.; Krahmer, R.L. 1992. Deterioration of fire-killed and fire-damaged timber in the Western United States. Gen. Tech. Rpt. PNW-292. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 27 p.

This paper is a very thorough review of literature prior to 1991. We may use this as our literature review with an additional review of the literature since 1991, plus any literature these authors may have overlooked.

Lowell, E.C.; Cahill, J.M. 1996. Deterioration of fire-killed timber in southern Oregon and northern California. Western Journal of Applied Forestry 11: 125-131.

Study took place in coastal mountains of southern Oregon and northern California. Species looked at were DF, GF, WF (true fir), PP, and SP. In this study, “cull” refers to <33% merchantable volume in cubic feet. Using a nested ANOVA, it was determined that most variability in decay was due to log position, rather than site, with one exception. In true fir, where site was accounted for, 1/3 of the variability was in the second and third years.

<u>Year 1</u>: Very little defect observed and volume loss was minimal. Some bark sloughing off top logs, especially in true fir. Weather checks primary scale deduction. Only 1% of logs had scale deductions for saprot, 5% for weather checks. Blue stain very significant in PP and SP, being complete in SP, and less in PP and streaked.

<u>Year 2</u>: Conks of *C. volvatus* appearing, bark sloughing occurring, and an increase of blue staining in PP, but still streaky. Saprot increased dramatically, 44% of logs, but volume affected was still small. Fourteen percent of logs had defect for checks. Mean cubic volume lost to checking (exact % not stated, but can be interpreted from bar graph) was higher than for saprot (exact % not stated, but can be interpreted from bar graph). Average small diameter of checked logs was 9.6”, and for saprot logs was 17.2”. In DF and true fir, half of the logs with checks were culled. In PP, just under 25% of checked logs were culled. Average percent volume loss was <10% for every species.

<u>Year 3</u>: Seventy-eight percent of logs contained saprot. No heartwood damage observed. Seventeen percent of all logs had checks. Average percent volume lost from non-cull logs was 23% for PP, 24% for SP, and 28% for true fir. DF% loss=38.5713 – (0.5531) * (log small end diam.)

<u>Summary</u>: The two primary defects were weather checks and saprot. Factors making trees more prone to weather checking are: hot, dry, windy sites; trees with thin bark; and after high intensity fires, trees in general may be more prone to checking. In year 2, pine logs >23” diameter lost more volume than true fir and DF logs: likely due to higher percent of sapwood corresponding to increase in saprot. Blue stain causes the largest economic loss associated with the use of 1-year dead pine sawtimber. Sapwood in PP makes up 50-75% of a tree’s gross cubic volume. No blue stain found in DF or true fir.

Wallis, G.W.; Godfrey, J.N.; Richmond, H.A. 1974. Losses in fire-killed timber. BC-X-88. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 11 p.

This paper was a continuation of Wallis and others 1971. They summarized for 2.5, 4, and 5 years after fire-killed. There was additional falling and yarding breakage. At 2.5 years the extra breakage was estimated to be 1.5%, at 4 years it was estimated to be 7% and at 5 years it was estimated to be 16% (*volume measurement unclear*). After 5 years, DF had heartwood borers penetrating up to 3” into the heartwood. After 5 years, there was 75% total volume decayed in western hemlock. At year 4, decay was minor in lower 3 to 4 feet of bole in DF. In WRC, decay was negligible after 5 years. Most decay fungi were brown rotters.

Summary:

1- salvage ASAP due to rapid deterioration

2- small dbh salvage first (it decays faster)

3- but large dbh lose peeler value fast

4- salvage decay susceptible species first

5- maybe fall fire-killed quickly and harvest when possible (due to inc in breakage over time

6- consider potential insect outbreaks

Wallis, G.W.; Richmond, H.A.; Godfrey, J.N.; Craig, H.M. 1971. Deterioration of fire-killed timber at Taylor River, Vancouver Island, British Columbia. BC-X-52. Victoria, BC: Canadian Forestry Service, Forest Research Laboratory. 15 p.

This study looked at mostly fire-killed Douglas-fir, 29 months after death.

Douglas-fir

Borers attacked Ninety-five percent of trees with no correlation with site or elevation. Twelve percent of volume decayed. Percent of decay increased with increased height in tree (*which is contrary to Hadfield and Magelssen's study*). Percent of sapwood decayed considerably less in immature timber than mature timber, but the percent total volume decayed was about the same for both. The authors listed the following fungi as responsible for most of the decay: *Stereum sanguinolentum*, *Amylostereum chailletii*, and *Fomes pinicola* (syn. *Fomitopsis pinicola*)- but there was no mention of isolations for identifying the fungi.

Western Hemlock

Lower bole infestation by ambrosia beetles and siricids was higher than found in Douglas-fir. In mature trees, 24% of total volume visibly decayed. Decay greatest in middle and upper bole, but decay relatively high throughout. Greater than 50% of immature volume was visibly decayed. Damage was consistently high at and above the first log. The fungi listed as causal agents of decay were: *Amylostereum chailletii*, *Fomes annosus* (syn. *Heterobasidion annosum*), and *Fomes pinicola* (syn. *Fomitopsis pinicola*).

Western Red Cedar

In mature trees, there were fewer borer attacks (22%) than found in Douglas-fir and western hemlock, but attacks in immature WRC equaled or exceeded immature DF and WH; borers had attacked all immature trees, with 67% considered "infested". Blue stain was in most trees, but decay was only found in a small pocket in one sample tree, so no appreciable loss.

Deterioration of Beetle-Killed Trees

Harvey, R.D., Jr. 1986. Deterioration of mountain pine beetle-killed lodgepole pine in northeast Oregon. R6-86-13. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 10 p.

> Author looking at deterioration in standing and down LPP and snag longevity in LPP in NE Oregon. <1% cubic foot volume lost due to advanced decay after 11 years from time of death. (*This low volume lost may be due to their sampling. In their latest sampling (1985) they checked for decay at cut stump and if none observed, then no more cuts were made. Other studies (see Wright and Wright 1954) have shown decay may be heavier further up the bole, so much decay may have been missed with this sampling technique*.) 25.3% fall down after 11 years. Summary: MPB killed LPP not significantly decayed for at least 10 years after death.

Mielke, J.L. 1950. Rate of deterioration of beetle-killed Engelmann spruce. Journal of Forestry. December: 882-888.

> Author looked at Engelmann spruce beetle-killed Engelmann spruce in Utah, dead for approximately 25 years. Eighty-four percent were still standing after 25 years, with smaller trees going down disproportionately. What had fallen appeared to have fallen gradually. Basal rots and root rots were the two most important factors in tree fall down. *F. pinicola* was the most common basal rot. Standing trees were sound except for occasional pockets of basal saprot (usually 1-2 feet above ground). Theory for why decay was so low to non-existent is the very dry conditions of the site, so fungi not able to take hold except at base of trees. In trees 3+ years' dead, moisture levels in both sap and heartwood are too low for fungi (<22%). All evidence indicates spruce will remain sound if they remain standing. In down spruce, decay was observed to start around weather checks which collect water. The "very common" and "fairly common" fungi associated with decay in standing and dead trees were: *F.pinicola, P.alboluteus, A.mellea, P.pini, L.sepiaria, P.circinatus, P.leucospongia*, and *S.abietinum*. Season checks the only defect of any consequence, but only important if product is lumber. Weather checking ceases once tree has dried out. Very few trees attacked by woodborers, and those that did, were confined to lower bole of larger trees. Damage was confined to outer sapwood, which is removed in the slabs when milled. Some trees had ambrosia beetle galleries. Observations of fire-killed spruce, they stand a long time, but most are down by 70 years. Rate of deterioration from decay in fallen trees is fairly rapid. All this indicates that ESB killed spruce trees in Colorado will remain standing and sound for at least 20 years.

Miller, J.M.; Keen, F.P. 1960. Biology and control of the western pine beetle; A summary of the first fifty years of research. Misc. Publication 800. Washington. DC: U.S. Department of Agriculture, Forest Service. 152 p.

> This report summarizes the information known at the time on western pine beetle in

ponderosa pine.

Borer damage. Several types of beetles, including ambrosia beetles, sapwood weevils, round-headed borers, and flat-headed borers attack dead trees at various time periods following death – some immediately, and others, several years later. Borers physically degrade wood through the feeding of the larvae and they also introduce fungi that assist in the deterioration process. Flat-headed and round-headed are the ones most likely to penetrate into the sapwood, or even down into the roots, and are important contributors in the deterioration of the main bole.

Stain. Blue stain is found in insect-killed trees almost immediately, but % sapwood affected is not high for the first 2 or 3 months after initial attack. Percentage of sapwood stained usually reaches its peak by the end of the first year, about the same time the new generation of beetles leave the tree. Presents data from Susanville, CA where, at the end of that first year, mill degrade due to stain was 47.1 %.

Sap rot. Sapwood decay begins within the first year following beetle attack. ***Fomes pinicola*** is the "most common cause" of sapwood rot in beetle-killed ponderosa pine. First appears as a yellowish or brownish stain in the sapwood, and eventually reduces the sapwood and heartwood into a brown, crumbly mass. This fungus is largely responsible for the eventual fall of beetle-killed snags. ***C. volvatus*** develops in the outer sapwood even before adults emerge from infested trees. Fruiting bodies are most plentiful the year following emergence (second year after death).

Tree fall. Wood of beetle-killed trees continues to break down, particularly near ground-line. Eventually, the snags fall and wood deterioration continues on the ground. Remainder of discussion covered Keen (1955), and those details are covered above under the Keen citation.

Panshin, A.J.; de Zeeuw, C. 1980. Textbook of Wood Technology; Structure, identification, properties, and uses of the commercial woods of the United States and Canada. 4th Edition. McGraw-Hill Book Co., Inc. New York: 374-376.

Sap stains are discolorations in sapwood of dead trees caused by non-decaying fungi. Heartwood is usually unaffected. These fungi derive their nourishment from food materials stored in cells of the sapwood. They do not usually deteriorate the cell walls of wood; penetration of wood cells usually occurs through the pits of the cell walls, and is mostly a mechanical action, rather than an enzymatic action, such as found in decay fungi.

Parry, D.L.; Filip, G.M.; Willits, S.A.; Parks, C.G. 1996. Lumber recovery and deterioration of beetle-killed Douglas-fir and grand fir in the Blue Mountains of eastern Oregon. Gen. Tech. Rep. PNW-GTR-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Authors looked at DF and GF killed by DFB and/or WSBW (0 to 4 years dead). DF averaged 161 years and 20" dbh, and GF averaged 121 years and 19" dbh. Saprot increased significantly with years dead. After 3 years dead there was 8.1% and 1.7% saprot in DF and GF, respectively. Most decay was due to *C. volvatus*. No conks of *F. pinicola* were present, even after 4 years dead. Saprot low, especially compared to west-side decay rates (Wright and Wright 1954. High amounts of checking were likely due to droughty conditions after tree death. Both saprot and checking increased with time since death. Few insects associated with defective wood, possibly because wood too dry with droughty conditions. Losses from breakage and handling were minor (0.5% to 3.8%) Weather checks increased from 1% to 5%, and saprot increased from 6 to 20%, from 1 to 4 years since death. Cubic foot volume recovery % (CR%) showed no difference between live and 1 year dead DF, but was significantly different for live vs. 3-4 year dead DF, and there was no difference between classes of dead GF.

CR% live vs. dead GF 8% loss

CR% live vs. 3-4 yr dead DF 15% loss

Contrary to popular belief, GF did not deteriorate as fast as DF or lose as much value as expected.

Thomas. G.P.; Craig, H.M. 1958. Deterioration by fungi of killed Douglas-fir in Interior British Columbia. Ottawa, Canada.: Department of Agriculture, Science Service, Forest Biology Division. 20 p.

Area of study had an average precipitation of 13-15”. Mortality agents varied, but usually consisted of 2 or more agents, such as frost/DFB, and fire/DFB/drought. Most DF seriously deteriorated after 5 years, though individuals seem very resistant. Heartrot present before death does not increase much after death in DF. Saprot: 12.4% volume reduction, heartrot: 4.3% volume reduction (3.9% in live trees) (It’s not clear how long the trees were dead). Thirteen species of wood rotting fungi were identified, with 2 species standing out: *F. pinicola* and *Polyporus abietinus*. The main heartrot (44% of heartrot) was *P. schweinitzii*. Most decay was due to brown rotters (14% out of a total of 16.6% decay volume) *P. abietinus* first to get established, *P. volvatus* rarely causes extensive damage.

Losses from saprot increased with increasing tree size and time dead- theorized this was due to thicker bark which keeps the bole at a higher moisture level. Appears deterioration decreased with increasing height above ground. Again, due to bark thickness, being much thinner at top so bole dries out faster.

DFB had a high association with saprot (after 4 years). Trees with light to no infestation (<2 galleries/square foot) had 5.7% decay, while trees that were heavily infested (>=2 galleries/square foot) had 11.3% decay. In short term (<=5 years), heartrot decay does not increase appreciable, but over a longer time period, this may change. *P. schweinitzii* appears to continue to decay after tree death- in this study the average volume lost was 4% greater in dead trees than in live trees. (*But also need to note that dead trees were larger than surrounding live trees*). The factors affecting deterioration: increases with tree size, increases with increased number of bark beetles, and increases with time.

Wright, E.; Wright, K.H. 1954. Deterioration of beetle-killed Douglas-fir in Oregon and Washington. Research Paper 10. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

End of first year after kill, principal loss is from sapstain. "Rot" moves through sap and into heartwood and heartwood is fairly rotten by year 5. After 8 years, trees have very little commercial value. Top breakage appears to accelerate decay. In many cases, *F. pinicola* sporophores directly associated with decay. Isolations show *F. pinicola* penetrated beetle killed trees extremely fast. Borers become more important with time. On a bd.ft. basis, all useable sapwood destroyed by end of second year (stain??). Early deterioration greatest in young stands, so should give highest priority to youngest age classes for salvage. Decay may not extend to ground, so ground checking for decay may give false data. Presence of *F. pinicola* rudimentary sporophores indicates advanced stage of decay- sapwood decayed and heartwood may be invaded. DFB galleries are closely associated with sapwood decay on recently killed trees- indicating DFB is introducing the fungi. Degree of deterioration for the first 2 years depends on time of year when initial DFB attack occurred. In spring (first flight) attacks, the decay is most severe due to the longer length of good growing time for the fungi. Breakage with felling increases with time since death. Decayed sapwood loses it resilience or elasticity, and loss of crown reduces cushioning when felled. Two years dead, fellers estimated an increase in breakage of 25%. Broken topped trees seem to deteriorate faster- assumedly due to entry of "top rots". Increase in fire hazard with increase in fuels from DFB-killed trees.

Fungal Biology and Insect Interactions

Borden, J.H.; McClark, M. 1970. Biology of *Cryptoporus volvatus* (Peck) Shear (*Agaricales polyporaceae*) in southwestern British Columbia: Distribution, host species, and relationship with subcortical insects. SYESIS 3: 145-154.

C. volvatus has been associated with fire-killed trees or trees infested with subcortical insects. This study looked at incidence of *C. volvatus* on fire-killed DF and PP, 2 years dead in B.C. Most collections made in areas with <40 inches of annual precipitation. *C. volvatus* was found to be associated with *Dendroctonus pseudotsugae* Hopkins and *Pseudohylesinus nebulosus* LeConte. Incidence of *C. volvatus* was 20% higher on DF than PP. If just woodborers present, a lower association with *C. volvatus* was found. When DFB present, the incidence increased from 34.4% to 100%. Occurrence and density of *C. volvatus* is strongly dependent on DFB attack. Frequency of *C. volvatus* was greater on trees of larger diameter in both DF and PP. There appears to be a threshold of 10" (due to DFB not attacking such small material?). The authors assume this is related to bark thickness- more rapid desiccation in thinner barked trees. Evidence indicates insects transmit the fungus. In this paper, the authors propose the vector to be *Temnochila virescens* (predator of bark beetles and other subcortical insects). The principal insects found are as follows:

Tree Species	Principal Insect at DBH
Douglas-fir	*Dendroctonus pseudotsugae*, woodborers, *Pseudohylesinus*
Ponderosa pine	*Ips*, woodborers, *Dendroctonus ponderosae, D. brevicomis*
Lodgepole pine	*D. ponderosae, Ips,* woodborers
Abies	Scolytidae

Castello, J.D.; Shaw, C.G.; Furniss, M.M. 1976. Isolation of *Cryptoporus volvatus* and *Fomes pinicola* from *Dendroctonus pseudotsugae*. Phytopathology 66: 1431-1434.

Authors trapped DFB, in flight and as pre-emerged adults, then plated whole beetles on selective medium. *Fomitopsis pinicola* was isolated more than twice as frequently from beetles excavated from galleries as from beetles trapped in flight. Further investigation revealed that the increased frequency of isolation of *F. pinicola* from pre-emerged adults versus those trapped in flight was inversely correlated with the total number of **other** organisms on the selective medium. *C. volvatus* and *F. pinicola* were isolated from both first- and second-flight beetles. The results of this study demonstrate the role of *D. pseudotsugae* in dissemination of *C. volvatus* and *F. pinicola* on DF in N. Idaho. Examinations of hundreds of fresh sporophores of *C. volvatus* over many years have not revealed a single specimen of DFB. The authors theorize the beetles pick up propagules of mycelium while tunneling through wood colonized by one or both fungi. This is due to the belief that *C. volvatus* is not wind disseminated, which is proven incorrect by Harrington (1980). Because *F. pinicola* is known to be wind disseminated, they theorize that bark beetles are probably not the principal vectors.

Gara, R.I.; Geiszler, D.R.; Littke, W.R. 1984. Primary attraction of the mountain pine beetle to lodgepole pine in Oregon. Ann. Entomol. Soc. Am. 77: 333-334.

Covered adequately in Geiszler and others 1980.

Geiszler, D.R.; Gara, R.I.; Driver, C.H.; Gallucci, V.F.; Martin, R.E. 1980. Fungi and beetle influences on a lodgepole pine ecosystem of south-central Oregon. Oecologia (Berl.) 46: 239-243.

The authors studied fire scar history of 130 year-old LPP in central Oregon. *Phaeolus schweinitzii* was found to be the principal pathogen in stained and decayed LPP. All fire-scarred trees had stain and/or decay. At the beginning of an outbreak, *D. ponderosae* may select trees weakened by *P. schweinitzii* with less regard to dbh. This study shows that beetles selected fire-scarred trees regardless of diameter at the start of an outbreak. *P. schweinitzii* likely lowers resistance of trees to bark beetle attack, but also may oxidize alpha-pinene to trans-verbenol, which is an aggregating pheromone for *D. ponderosae*. High percentages of fire scarred trees were being attacked by MPB which could have been due to selecting larger dbh trees, which are more likely to have fire scars, but MPB killed more fire scarred trees than not scarred trees at each diameter class.

Graham, D.P. 1962. What is known about disease potential of wind-thrown timber; A summary report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 8 p.

This is a general summary of information about fungal deterioration of wind-thrown timber – written for Washington and Oregon. Pathological deterioration begins almost immediately and will continue at various rates depending upon trees species, size, and environment. He lists the following tree species in order of the most decay-susceptible to the least: western hemlock, true firs, spruce and second growth Douglas-fir, pines, old Douglas-fir and western larch, and western redcedar. The most susceptible species may be minimally salvable in as little as 3 years, whereas the more resistant may be salvable for 10 to 20+ years.

Wood-decay fungi require a suitable substratum plus proper moisture, temperature, and light conditions. Of these factors, the moisture/temperature relationship is the most important. Wood-decay fungi will not grow at wood moisture content of less than 20 percent, nor will they grow in waterlogged wood. Growth is optimum at 70 – 85°F, and is slow below 50°F and over 100°F.

Dubreuil, S.K. 1981. Occurrence, symptoms and interactions of *Phaeolus schweinitzii* and

associated fungi causing decay and mortality of conifers. Moscow, ID: PhD. Dissertation: University of Idaho. 154 p.

Relating to fire, root contacts and wounds inconsequential as means of infection and spread of *P. schweinitzii* in stands. Other work indicates infection of basal scars minimal compared to root infections.

Harrington, T.C. 1980. Release of airborne basidiospores from the pouch fungus, *Cryptoporus volvatus*. Mycologia 72: 926-936.

Emergence, development and sporulation of basidiocarps of *C. volvatus* showed no apparent relationship to precipitation. Total airborne spore production was comparable with that of other annual polypores whose spores are unquestionably wind disseminated. *C. volvatus* develops and releases spores during months of little or no rainfall. Resinous crust of *C. volvatus* basidiocarps may also be an adaptation that slows moisture loss. It is noteworthy that *C. volvatus* is not restricted to fruiting at or near ground level- it readily fruits up high which is more advantageous for dissemination by bark beetles. Two most common bark beetle associations are with *D.*

pseudotsugae and *S. ventralis*. Sporulation and invasion of dead and dying trees by competing fungi during bark beetle flight periods appears more likely to exclude *C. volvatus* from high summer-rainfall areas than a paucity of insect vectors. The volva/ostiole appears more likely a xerophytic adaptation than an adaptation for insect dispersal. It enables it to produce basidiospores during periods of low precipitation and relative humidity associated with bark beetle flight periods. All evidence points to airborne basidiospores as the primary means of dissemination.

Wind dissemination should be considered the major means of dispersal of *C. volvatus* as in other Polyporaceae.

Harrington, T.C. 1993. Biology and taxonomy of fungi associated with bark beetles. IN: Schowalter, T.D.; Filip, G.M., eds. Beetle-Pathogen Interactions in Conifer Forests. Academic Press: 37-42.

This review provides information on the biology of blue stain fungi and their associations with bark beetles. Blue stain fungi in general are not well adapted for aerial dissemination. They have very sticky spores that adhere quite well to insects, which makes them well adapted for insect dispersal.

Snag Retention

Dahms, W.G. 1949. How long do ponderosa pine snags stand? Research Note 57. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 3 p.

Study was done for ponderosa pine on the Pringle Falls Experimental Forest.

Ten years after fire, about 50% were down, and after 22 years, 78% had fallen. Also showed that very few fell within the first 2 years. The fall rate accelerated between year 3 and about year 14 and then started to level off. Smaller snags tended to fall sooner than larger ones. Average inside-bark-diameter of all down trees after 22 years = 22 inches, while those still standing averaged 26 inches.

Harrington, M.G. 1996. Fall rates of prescribed fire-killed ponderosa pine. INT-RP-489. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station 7 p.

Tree fall. Harrington studied fall rates of fire-killed ponderosa pine in southwestern Colorado. Majority of trees were 4 to 11 inches dbh. The fires were prescribed burns carried out in the spring, summer or fall. Study site was evaluated for 10 years following the fire. Probability of tree fall after death by fire is largely determined by 2 factors: the percent crown scorch and the amount of time it takes a tree to die after injury by fire. Overall, trees that died within the first year had a higher probability of imminent failure than those that initially survived but died in subsequent years. However, the crown-scorch factor also appeared to be important. Trees that died within the first year and had greater than 80% crown scorch had an 82% probability of falling within 10 years after the fire. Trees with less than 80% crown scorch, yet died within the first year had a 75% probability of falling. Trees with less than 80% crown scorch that survived for 2-3 years post-fire only had a 27% probability of falling within the 10-year period. In this study, while the smaller diameter classes had a higher mortality rate, which provided more trees available for falling, tree fall rates were similar among size classes; however, Harrington suggests that this may be due to the range of tree diameters in this study being fairly small. He hypothesizes that the difference in fall rates may be tied to resin flow in injured trees and how that affects response to beetle attacks and spread of decay fungi. Trees that die quickly or experience heavy crown scorch are not able to allocate energy for resin production and transport. Injured trees, even if they eventually die, are capable of at least initiating resinosus, and higher resin concentrations would retard stem decay and lengthen the time a tree would stand after death. General conclusion: 75-80% of trees that die in the first post-burn year will fall within 10 years. Tree with extended use as snags will be those with moderate to low crown scorch that remain alive for at least 2 years after injury.

Keen, F.P. 1955. The rate of natural falling of beetle-killed ponderosa pine snags. Journal of Forestry 53: 720-724.

Keen studied the fall of beetle-killed ponderosa in northern California and southern Oregon. Few trees fell the first two years and 85% of dead trees were still standing after 5 years. After that, the butts become “riddled” with woodborers and decay and the trees begin falling at a rapid rate. Most of the fall occurs between year 5 and 12. After 10 years, 40% were still standing. After year 12, the rate of fall slows down and the more resistant, large diameter snags remain standing for many years. There was an indication that soils may be important in determining fall rates in that snags stood longer on dry pumice soils than on moist clay and loam soils. Trees with pitchy butts, those on dry sites, and those charred and “case-hardened” by fire were the last ”ghost trees” still standing in areas where beetle epidemics had occurred decades before.

Lyon, L.J. 1977. Attrition of lodgepole pine snags on the sleeping child burn, MT. Research Note INT-219. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Lodgepole pine snag attrition the first two years following fire was negligible (~ 1%). Nearly half fell within 5 years. Only 28% were still standing after 10 years, and only 15% were still standing after 15 years. Snags less than 3” had an annual attrition of nearly 28%, and most were gone in 15 years. For snags greater than 3”, fall rate was variable, but averaged an annual rate of 8.4%. The largest snags, greater than 12”, 42.8 percent were still standing after 15 years.

Schmid, J.M.; Mata, S.A.; McCambridge, W.F. 1985. Natural falling of beetle-killed ponderosa pine. Research Note RM-454. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 3 p.

Trees studied were ponderosa pine in the Colorado Front Range killed by mountain pine beetle. Tree diameters ranged from 7 to 22 inches. No trees fell the first two years.

Thereafter, the fall rate averaged about 3 – 5% per year, unless winds exceeded 75 mph. Trees generally broke off within 2 feet of ground level.

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